Optimizing Multi-Site Production Planning and Scheduling with a Hybrid Genetic Algorithm

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ABSTRACT

As the economic environment continues to change rapidly, so does the demand placed on industries to meet ever expanding orders. In order to meet this demand, the need to expand is matched by the need to utilize existing facilities, and increase efficiency. As a result, conventional order management programs often no longer suffice. Single-site planning has developed into multi-site planning, leading to distance problems between sites as well as problems regarding information transfers between them. This study aims at constructing a decision model of an integrated multi-site production scheduling problem. To support multi-site factories with their mass orders, based on the premise that they were under total order management systems, the decision model considered such complicated factors as the product market features, due date, production scheduling, and order profit and capacity of each site. Most real-world scheduling problems involve multiple objectives which may be conflicting with each other. In addition, the effect factors taken into account by previous multi-objective scheduling research are essentially quantitative factors. However, more qualitative factors also have to be considered related to organizations' operating messages. We propose an integrated production scheduling model and use hybrid genetic algorithm methods as solution procedures.

Keywords: Multi-Site Scheduling Problem, Assignment Problem, Genetic Algorithm**,** Multi-Objective Scheduling, Allocation Problem

INTRODUCTION

In business, production activities play an important role in determining a company's operating cost. In modern management, organizations interact with the environment and pursue objectives according to their specific mission (Tavares, 2000). Scheduling is an important tool for manufacturing and engineering, as it can have a major impact on the productivity of a process. In manufacturing, the purpose of scheduling is to minimize production time and costs by directing a production facility regarding what to make, when, with which staff, and on which equipment. Production scheduling aims to maximize the efficiency of the operation and reduce costs (Pinedo, 2005). In general, the production plan and scheduling of orders are both very complicated.

Multi-site scheduling literature was first pointed out in Thierry *et al.* (1995), who stated that problems could be solved by improving coordination between different production units in the field of production planning and control for a multi-site production. A multi-site production takes place when the production facilities of an international company are located in different geographical sites. To solve this problem, a centralized approach is chosen and a multi-site planning integrated system is built in relation to the local planning and control systems of the different production sites. Bullinger *et al.* (1997) proposed an object-oriented model to project multi-site production. Sauer *et al.* (1998) stated that global level data were normally aggregated, imprecise, or estimated. Most previous methods focused on local production sites without giving consideration to the coordination issue. They proposed a global view of multi-site company operations. During the last ten years, various papers have discussed multi-site scheduling problems. However, there is still a wide range of problems that exist due to different types of factories each having its own set of priorities. The firm in our empirical study in is a machine tool company located in central Taiwan.

This study aims at constructing a decision model of an integrated multi-site production scheduling problem, and a novel approach hybrid genetic algorithm is applied into this combinatorial problem. In this empirical study, we demonstrate that firms can improve their profits through reducing costs such as penalties for job tardiness, etc. The rest of the paper is organized as follows: Section 2 illustrates the literature review; section 3 depicts the construction of a scheduling model; section 4 describes the heuristic process and the conclusion is summarized in section 5.

LITERATURE REVIEW

During the last decade, a variety of multi-site scheduling techniques have been developed and applied in practice. Pirkul and Jayaraman (1998) presented a mixed integer programming formulation for the supply chain management problem with capacitated plants and warehouses. They proposed an efficient heuristic based on Lagrangian relaxation of the multi-site scheduling problem. Roux *et al.* (1999) reported a method which alternated between solving a planning problem in which lot-sizes were computed for a given sequence of jobs on each machine, and a scheduling problem in which sequences were computed for each site. The lot-sizing and scheduling problems can also be solved in parallel.

Vercellis (1999) proposed the adaptation of master production planning (MPS) concepts to multi-site production scheduling. Timpe and Kalltrah (2000) proposed a mixed linear integer programming model to a multi-site scheduling network. Guinet (2001) suggested a two-level production management to control multi-site production systems divided into global multi-site planning and local multi-site scheduling. Sambasivan and Schmidt (2002) presented a heuristic procedure for solving multi-plant, multi-item, capacitated lot sizing problems with inter-plant transfers. The solution procedure used the solution for the non-capacitated problem as a starting point. Moon *et al*. (2002) proposed an integrated process planning and scheduling (IPPS) model for the multi-plant supply chain (MSC), which behaves liked a single company through strong coordination and cooperation toward mutual goals. Leung *et al.* (2003) addressed the problem of aggregate production planning (APP) for a multinational lingerie company in Hong Kong. The multi-site production planning problem considered the production loading plans among manufacturing factories subject to certain restrictions, such as production import/export quotas imposed by the regulatory requirements of different nations, the use of manufacturing factories/locations with regard to customer preferences, as well as production capacity, workforce levels, storage space and resource conditions of the factories. In that paper, a multi-objective model was developed to solve the production planning problems, in which the profit was maximized but production penalties resulting from going over/under quotas and the change in workforce level were minimized. Other related studies included a multi-site scheduling system proposed by Gnoni *et al*. (2003), a systematic approach to solving the multi-site resources planning problem proposed by Papageorgiou (2004), and a deterministic model for solving a multi-site and multi-warehouse problem reported by Jolayemi and Olorunniwo (2004).

A genetic algorithm (GA) is a search technique used in computing to find exact or approximate solutions to optimization and search problems. Genetic algorithms are categorized as global search heuristics. Genetic algorithms are a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover (Schmitt, 2001). GA was introduced as early as 1954 by Nils Barricelli. Genetic algorithms are implemented as a computer simulation in which a population of abstract representations (called chromosomes or the genotype or the genome) of candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem evolves toward better solutions (Koza, 1992). The solutions are represented in binary as strings of 0 and 1, but other encodings are also possible. The evolution usually starts from a population of randomly generated individuals and happens over generations. In each generation, the fitness of every individual in the population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness), and modified (recombined and possibly randomly mutated) to form a new population. The new population is then used in the next iteration of the algorithm (Holland, 1975). The algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population. If the algorithm has terminated due to a maximum number of generations, a satisfactory solution may or may not have been reached. It typically contains: a genetic representation and a fitness function to be evaluated (Vose, 1999). Holland (1976) simulated natural selection and proceeded with crossover and mutation. His research has become a popular citation. Our study call GA module form, the Matlab library, is based on his research. In recent years, GA is often mutated by other algorithms to design a new hybrid genetic algorithm (HGA), such as tabu search (Diaz *et al.*, 2008; Degertekin *et al.*, 2008; Drezner, 2008). We also design a HGA for our research problem.

Although some literatures are available on multi-site scheduling problems, there is only a small amount of this literature focused on machine tool industries. This is also the case with regard to the literature available on discussing hybrid genetic algorithm applied to multi-site scheduling problem. Besides, our objective is derived from real-world scheduling problems. This study would offer multi-site firms further information for reducing the tardy penalties.

A SCHEDULING MODEL

This research establishes a non-linear mathematical program which simulates the structure of multi-site production scheduling. Through splitting orders of parts of each generation in different satellite plants, the evolution of sequence of order assignment of parts in each generation reached optimized performance. The model is described as follows:

Notations

p : order of parts number ($p = 1, \cdots, P$);

t : production stage ($t = 1, \cdots, T$);

i : production stage number of order of parts ($i = 1, \cdots, I$);

j : site number of production stage of order of parts ($j = 1, \cdots, J^i$);

m : machine number ($m = 1, \cdots, M_{J^i}$)

Parameters

$P_{(i,j)mpt}$: processing time at order of parts p, order of part stage i, site j, machine m, stage t

$S_{(i,j)mpt}$: setup time at order of parts p, order of part stage i, site j, machine m, stage t

$Q_{(i,j)mpt}$: quantity at setup time at order of parts p, order of part stage i, site j, machine m, stage t

$cap_{(i,j)t}$: capacity at order of part stage i, site j, stage t

$cap_{(i,j)m}$: capacity at order of part stage i, site j, machine m

DD_p : due date of order of parts number p

α_1 : weighted factor of machine utilization

α_2 : weighted factor of due date

α_3 : weighted factor of makespan

W_1 : weighted factor of quantitative impact

W_2 : weighted factor of qualitative impact

$\alpha_1 + \alpha_2 + \alpha_3 = 1$;

$W_1 + W_2 = 1$

Decision Variables

$L_{(i,j)p}$: size at order of parts p, order of part stage i, site j
$l_{(i,j)np}$: splitting numbers of size at order of parts p, order of part stage i, site j
$l_{(i,j)np} = \frac{Q_{(i,j)pt}}{L_{(i,j)p}}$)
$T_{(i,j)mpt}$: start time at order of parts p, order of part stage i, site j, machine m, stage t
$C_{(i,j)mpt}$: completion time at order of parts p, order of part stage i, site j, machine m, stage t
$U(C_{(i,j)mpt})$: satisfaction in completion time at order of parts p, order of part stage i, site j, machine m, stage t

Objective Function

$$Max\ \ W_1 \cdot \sum_{t=1}^{T} \left(\begin{array}{l} \alpha_1 \cdot \sum_{i=1}^{I}\sum_{j=1}^{J^i}\sum_{m=1}^{M_{J^i}}\sum_{n=1}^{N}\sum_{p=1}^{P} \left(\frac{S_{(i,j)mpt} + \left(L_{(i,j)p} \cdot l_{(i,j)np} \cdot P_{(i,j)mpt}\right)}{C_{(i,j)mpt}} \cdot \frac{1}{\sum_{m=1}^{M_{J^i}} m} \right) + \\ \alpha_2 \cdot \sum_{i=1}^{I}\sum_{j=1}^{J^i}\sum_{m=1}^{M_{J^i}}\sum_{p=1}^{P} \left(\frac{U(C_{(i,j)mpt})}{p} \right) + \alpha_3 \cdot \sum_{i=1}^{I}\sum_{j=1}^{J^i}\sum_{m=1}^{M_{J^i}}\sum_{p=1}^{P} \left(\frac{\min\left\{C_{(i,j)mpt} - T_{(i,j)mpt}\right\}}{C_{(i,j)mpt}} \right) \end{array} \right) +$$
$$W_2 \cdot (1 - p(x))$$

A simplified version of the objective function can be stated as:
Max $W_1 \cdot$ ($\alpha_1 \cdot$ (average utilization of machine)+ $\alpha_2 \cdot$ (average satisfaction of completion time)+ $\alpha_3 \cdot$ (makespan performance)+ $W_2 \cdot$ (1-penalty function)

Constraints

(1) Due date constraints
$$C_{(i,j)mpt} - T_{(i,j)mpt} \le DD_p \quad \forall i,j,m,p,t$$
(2) Constraints of batch processing time
$$\left\{C_{(i,j)mpt} - T_{(i,j)mpt}\right\}_{MAX} \ge S_{(i,j)mpt} + \left(T_{(i,j)mpt} + L_{(i,j)p} \cdot l_{(i,j)np} \cdot P_{(i,j)mpt}\right) \quad \forall i,j,m,p,t$$
(3) The same operation with different machines
$$T_{(i',j')mpt} \ge S_{(i,j)mpt} + \left(T_{(i,j)mpt} + L_{(i,j)p} \cdot l_{(i,j)np} \cdot P_{(i,j)mpt}\right) \quad \forall i,j,m,p,t$$
(4) Different operations with the same machine
$$T_{(i,j)mpt} \ge S_{(i',j')mpt} + \left(T_{(i',j')mpt} + L_{(i,j)p} \cdot l_{(i,j)np} \cdot P_{(i',j')mpt}\right) \quad \forall i,j,m,p,t$$

(5) Constraints of Capacities

$$S_{(i,j)mpt} + \left(T_{(i,j)mpt} + L_{(i,j)p} \cdot l_{(i,j)np} \cdot P_{(i,j)mpt}\right) \leq cap_{(i,j)m} \cdot m \quad \forall i, j, m, p, t$$

(6) Constraints of lot sizing

$$L_{(i,j)p} \cdot l_{(i,j)np} \leq Q_{(i,j)mpt} \ \forall i, j, m, p, t$$

(7) Non-negative constraints

$$L_{(i,j)p} \geq 0 \quad \forall i, j, p$$

$$T_{(i,j)mpt} \geq 0 \quad \forall i, j, m, p, t$$

$$C_{(i,j)mpt} \geq 0 \quad \forall i, j, m, p, t$$

$$U(C_{(i,j)mpt}) \geq 0 \ \forall i, j, m, p, t$$

Description of objective function

The objective function designed in this study is established across two parts: a multi-objective function and a penalty function. The multi-objective function is the performance indicator, to evaluate the allocation of the site, while the penalty function is obtained from the sequence. The weights in objective function, W_1 and W_2 , were derived by the Analytic Hierarchy Process (AHP).

Description of constraints

Equation (1) illustrates that completion time subtracts the release time, should be shorter than due date. Eq. (2) describes that when one manufactures the order of parts, due to the restriction of batch processing time of machines, one must satisfy its constraints. Eqs. (3) and (4) state the constraint of sequences of manufacture of orders of parts. Eq. (5) describes manufacture batch of order of parts should satisfy the constraint of plant capacity. Eq. (6) states that lot-size should satisfy the machine capacities. Eq. (7) illustrates non-negativity.

Heuristic Solution Process

The heuristic solution process is described as shown in Figure 1. The GA (Holland,1976) was described in Figure 1 without tabu search. It spends too much computation time, and does not produce a good optimal solution. Tabu is used for exclusion of some population (Cvijovic and Klinowski, 1995). In our hybrid genetic algorithm, we successfully add some restrictions of tabu consideration in order to accelerate the process and to generate a better optimal solution.

Our Hybrid Genetic Algorithm (HGA) is stated as follows:

Step 1:

1.1 Randomly selects an operation to proceed.

1.2 The set of sequence defines as S.

Step 2:

2.1 The size of the sequence is M, and is searched Z times.

2.2 The optimal is sequence S*.

2.3 The objective function is G(S*)=G(I).

2.4 Set S_1＝S and Z=1.

Step 3:

- Search for S_z's neighborhood, S^1, S^2,…, S^{N-1} and filling S^1, S^2,…,S^{N-1}, back in set.
- Check if the above violates the restriction of sequence; otherwise, proceed with adjustment.
- If not, then calculates its objective function values $G(S^1)$, $G(S^2)$,…, $G(S^{N-1})$, where N is the job number.

Step 4:

4.1 From $G(S^1)$, $G(S^2)$,…, $G(S^{N-1})$, selects the optimal value $G(S_z^*)$, where it does not belong to the tabu list.

4.2 If $G(S^*) < G(S_z^*)$, then $S^* = S_z^*$.

Step 5:

5.1 Updates the tabu list by FIFO (first-in-first-out);

5.2 Z++;

5.3 If z = Z, then Stop.

Step 6:

6.1 Replaces initial set S by S *, and proceeds with the GA procedure.

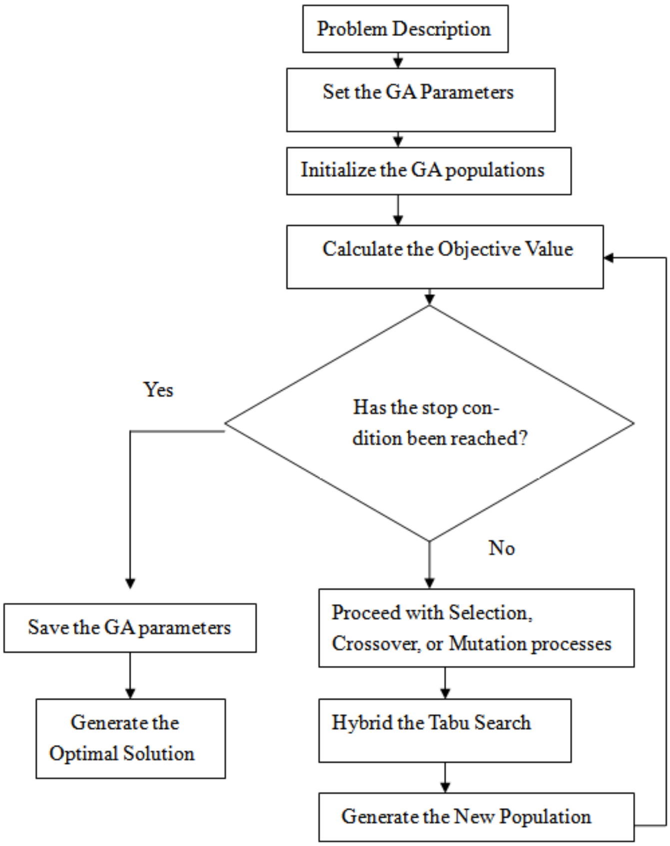

Figure 1: Flow Chart of a Hybrid Genetic Algorithm

RESULTS AND DISCUSSION

The experiments are processed by Matlab 6. The GA is created by calling the GA module from the Matlab library. The HGA is coded from Matlab programming and based on the steps as mentioned in section 4. After intensive calculations using a Pentium 4 PC, the optimal scheduling result is computed. The multi-objective values are shown in Tables 1 to 6, and plot at Figure 2. To compare the utilization of a machine using GA (in Table 1) and HGA (in Table 2), HGA totally outperforms GA. The managerial meaning is increasing the utilization of the machine. When comparing the satisfaction of completion time using GA (in Table 3) and HGA (in Table 4), once again the HGA outperforms GA. The managerial meaning for this is an increase in overall customer satisfaction due to a reduction of tardiness. To compare the makespan of GA (in Table 5) and HGA (in Table 6), the HGA outperforms GA on a consistent basis. The managerial meaning is a reduction in the overall operational cost (such as electric power or manpower fees). Therefore, in Figure 2, the objective value of HGA is better than GA.

Table 1: Utilization of Machine (GA)

	M1	M2	M3	M4	M5	M6	M7	M8
Site 1	0.6753	0.7716	0.4991	0.4776	0.7609	0.6574	0.6549	0.6470
Site 2	0.6489	0.5806	0.5294	0.3461	0.5635	0.3910	0.5672	0.6898
Site 3	0.5924	0.5161	0.4293	0.3051	0.4171	0	0.4425	0.5882

Table 2: Utilization of Machine (HGA)

	M1	M2	M3	M4	M5	M6	M7	M8
Site 1	0.6148	0.8117	0.9050	0.4811	0.6272	0.5948	0.5617	0.8467
Site 2	0.7963	0.5806	0.5865	0.8267	0.5665	0.4607	0.5332	0.5400
Site 3	0.3889	0.5161	0.7747	0.3051	0.4496	0.6632	0.4307	0.5882

Table 3: Satisfaction of Completion Time (GA)

Order No.	1	2	3	4	5	6	7	8	9	10	Avg
Due Date	55	100	104	121	60	72	80	110	77	50	
Completion Time	86.1	85.5	81.5	77	48	70.3	81.3	93.5	93.1	52.5	
Due Date Satisfaction	0	1	1	1	1	1	0.87	1	0	0.75	**0.762**

Table 4: Satisfaction of Completion Time (HGA)

Order No.	1	2	3	4	5	6	7	8	9	10	Avg
Due Date	55	100	104	121	60	72	80	110	77	50	
Completion Time	106.5	85.5	80.8	78.8	61.8	64.8	80.3	90.6	61.6	54.5	
Due Date Satisfaction	0	1	1	1	0.82	1	0.97	1	1	0.55	**0.834**

Table 5: Makespan Performance (GA)

		Operation RT-CT	Operation RT-CT	Operation RT-CT	Operation RT-CT	Operation RT-CT	Operation RT-CT	Operation RT-CT
Site 1	M1	6-1	2-3	1-4	4-6			
		0 17	29 43	48.1 53.1	61 77			
	M2	7-1	9-1	3-2	6-3	10-4	2-4	8-4
		0 7.5	7.5 12	21 30	30 38.5	38.5 42.5	43 59	66.6 75.1
	M3	3-1	10-3	8-5	9-6			
		0 21	29 36.5	75.1 82.1	82.1 93.1			
	M4	4-3	3-3	9-5				
		14 24	30 37	52 67				
	M5	4-2	10-2	3-4	9-4	6-5	2-5	
		5.5 14	14.1 25.1	37 45	45 52	52 58.3	59 76	
	M6	4-1	8-2	10-5	1-5			
		0 5.5	14 29	42.5 52.5	53.1 66.1			
	M7	7-2	5-3	9-3	4-5	8-3	2-6	
		7.5 14.1	20.5 30	31 37.6	43 61	61 66.6	76 85.5	
	M8	2-1	10-1	6-4	7-4	1-6	8-6	
		0 7.6	7.6 14.1	38.5 50.5	50.5 57.5	66.1 86.1	86.1 93.5	
Site 2	M1	5-1	7-3	1-4				
		0 7.5	14.1 36.1	48.1 53.1				
	M2	7-1	3-2	6-3	10-4	8-4		
		0 7.5	21 30	30 38.5	38.5 42.5	66.6 75.1		
	M3	1-1	5-2	2-2	10-3	8-5		
		0 11	11 20.5	20.5 29	29 36.5	75.1 82.1		
	M4	6-2						
		17 26						
	M5	4-2	3-4	6-5	7-5			
		5.5 14	37 45	52 58.3	58.3 81.3			
	M6	4-1	10-5	6-6				
		0 2.25	42.5 52.5	58.3 70.3				
	M7	7-2	5-3	9-3	1-3	8-3	2-6	
		7.5 14.1	20.5 30	31 37.6	37.6 48.1	61 66.6	76 85.5	
	M8	2-1	10-1	6-4	7-4	3-5	8-6	
		0 7.6	7.6 14.1	38.5 50.5	50.5 57.5	57.5 81.5	86.1 93.5	
Site 3	M1	5-1	9-2	1-4				
		0 7.5	12 31	48.1 53.1				
	M2	9-1	4-4					
		7.5 12	24 43					
	M3	1-1	5-2	2-2	9-6			
		0 11	11 20.5	20.5 29	82.1 93.1			
	M4	8-1	1-2					
		0 14	14 22					
	M5	5-4	6-5					
		30 48	52 58.3					
	M6	4-1						
		0 2.25						
	M7	7-2	9-3	1-3	8-3			
		7.5 14.1	31 37.6	37.6 48.1	61 66.6			
	M8	2-1	7-4	8-6				
		0 7.6	50.5 57.5	86.1 93.5				

RT: Release time
CT: Completion time

Table 6 Makespan Performance (HGA)

		Operation		Operation		Operation		Operation		Operation		Operation	
		RT-CT		RT-CT		RT-CT		RT-CT		RT-CT		RT-CT	
Site 1	M1	9-2		2-3		7-3		4-6					
		3	22	22	26.6	48.6	59.6	73.5	78.8				
	M2	9-1		7-1		6-3		10-4		8-4		2-4	
		0	3	3	8	26	34.5	36.5	44.5	45.6	54.1	54.1	62.1
	M3	3-1		10-3		9-6		8-5					
		0	21	29	36.5	50.6	61.6	61.6	68.6				
	M4	8-1		6-2		4-3		3-3					
		0	7	17	26	28	38	39	46				
	M5	4-2		9-4		6-5		3-4		7-5			
		11	28	28.6	35.6	46.5	52.8	52.8	68.8	68.8	80.3		
	M6	4-1		8-2		6-6		1-5					
		0	11	14	19	52.8	64.8	73.5	86.5				
	M7	9-3		8-3		1-3		4-5		2-6			
		22	28.6	28.6	45.6	48	58.5	58.5	67.5	79.1	85.5		
	M8	2-1		10-1		6-4		7-4		3-5		1-6	
		0	7.6	7.6	12	34.5	46.5	59.6	66.6	68.8	80.8	86.5	106.5
Site 2	M1	6-1		2-3		7-3		4-6					
		0	17	22	26.6	48.6	59.6	73.5	78.8				
	M2	9-1		7-1		6-3		8-4		2-4			
		0	3	3	8	26	34.5	45.6	54.1	54.1	62.1		
	M3	1-1		2-2		5-2		10-3		9-6			
		0	11	11	19.5	19.5	29	29	36.5	50.6	61.6		
	M4	1-2		9-5									
		11	19	35.6	50.6								
	M5	10-2		6-5		5-4		2-5					
		12	23	46.5	52.8	52.8	61.8	62.1	79.1				
	M6	8-2		10-5									
		14	19	44.5	54.5								
	M7	9-3		7-2		4-5		2-6					
		22	28.6	28.6	48.6	58.5	67.5	79.1	85.5				
	M8	2-1		10-1		6-4		7-4		3-5			
		0	7.6	7.6	12	34.5	46.5	59.6	66.6	68.8	80.8		
Site 3	M1	5-1		2-3		1-4		4-6					
		0	15	22	26.6	58.5	73.5	73.5	78.8				
	M2	9-1		7-1		3-2		4-4					
		0	3	3	8	21	39	39	58				
	M3	1-1		2-2		5-2		8-5					
		0	11	11	19.5	19.5	29	61.6	68.6				
	M4	8-1											
		0	7										
	M5	6-5		5-4		7-5							
		46.5	52.8	52.8	61.8	68.8	80.3						
	M6	8-2		10-5									
		14	19	44.5	54.5								
	M7	9-3		5-3		1-3		2-6					
		22	28.6	29	48	48	58.5	79.1	85.5				
	M8	2-1		10-1		7-4		8-6					
		0	7.6	7.6	12	59.6	66.6	68.6	90.6				

RT: Release time
CT: Completion time

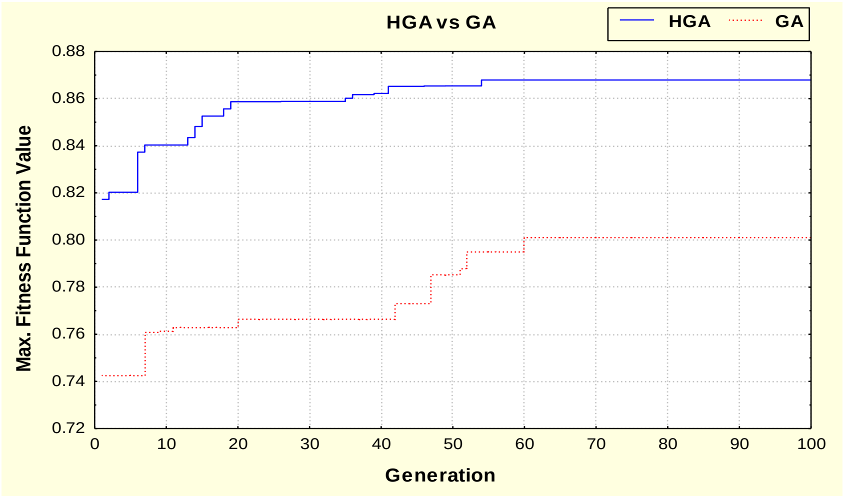

Figure 2: The Comparison of HGA and GA (Objective Value)

In a scheduling problem, it represents a sequence. 100 generations represent 100 different sequence results. In GA, the same sequence may exist within 100 different sequences. However, the same sequence will not exist in HGA due to the hybrid's tabu list. In Figure 3, under the same number of generations (100), HGA is better than GA in each batch of orders (10, 20, 30). We force the program to stop under a pre-defined computation time, and HGA is better than GA in each batch of orders (10, 20, 30) in Figure 4.

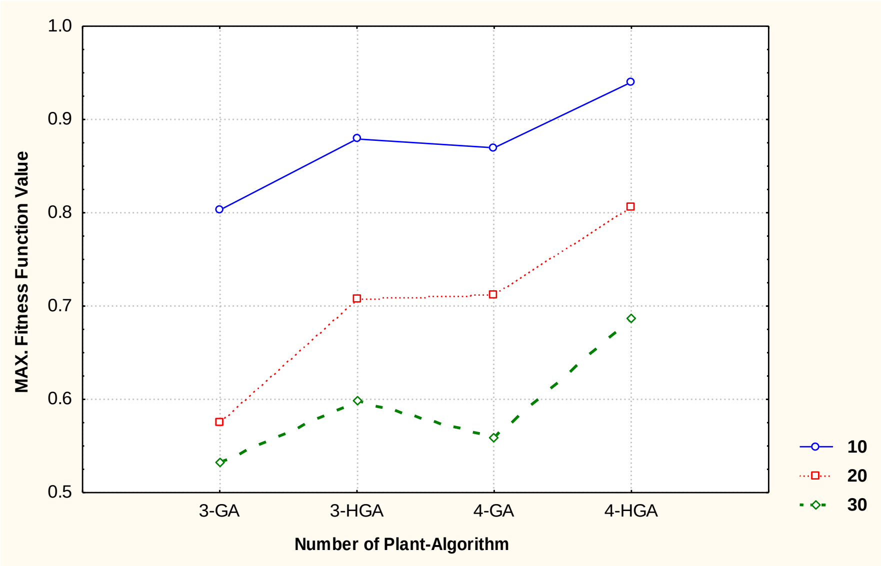

Figure 3: Performance Comparison of Different Number of Orders (under the same generations)

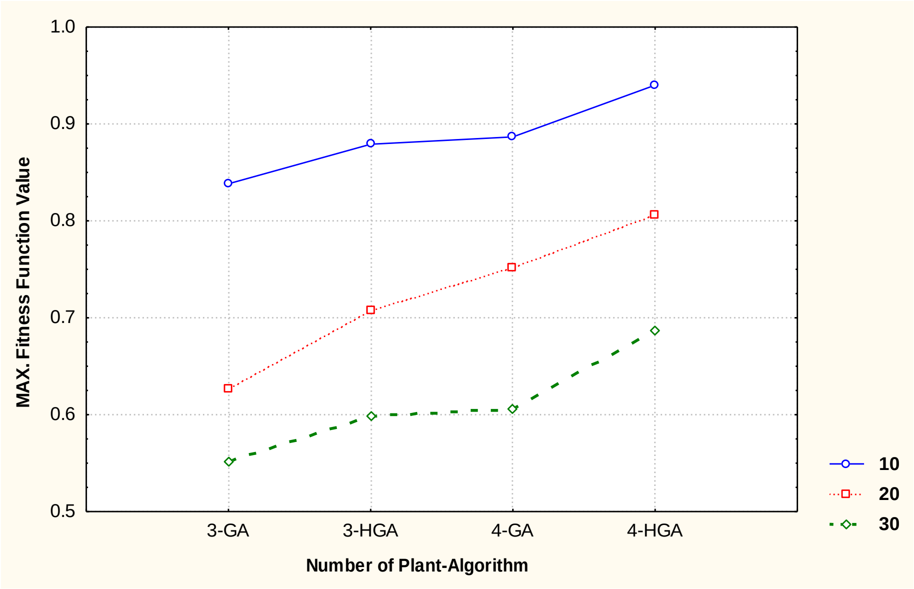

Figure 4: Performance Comparison of Different Number of Orders (under the same computation time)

In Table 7, we show an empirical application of scheduling. Based on this recommendation, the firm can easily deal with their orders.

Table 7: Orders Sequence

Order No.	Operation	Number of Batches	Site No.	Release Time	Completion Time
1	1	2	2, 3	0	11
	2	1	2	11	19
	3	2	1, 3	48	58.5
	4	1	3	58.5	73.5
	5	1	1	73.5	86.5
	6	1	1	86.5	106.5
2	1	3	1, 2, 3	0	7.6
	2	2	2, 3	11	19.5
	3	3	1, 2, 3	22	26.6
	4	2	1, 2	54.1	62.1
	5	1	2	62.1	79.1
	6	3	1, 2, 3	79.1	85.5
3	1	1	1	0	21
	2	1	3	21	39
	3	1	1	39	46
	4	1	1	52.8	68.8
	5	2	1, 2	68.8	80.8

4	1	1	1	0	11
	2	1	1	11	28
	3	1	1	28	38
	4	1	3	39	58
	5	2	1, 2	58.5	73.5
	6	3	1, 2, 3	73.5	78.8
5	1	1	3	0	15
	2	2	2, 3	19.5	29
	3	1	3	29	48
	4	2	2, 3	52.8	61.8
6	1	1	2	0	17
	2	1	1	17	26
	3	2	1, 2	26	34.5
	4	2	1, 2	34.5	46.5
	5	3	1, 2, 3	46.5	52.8
	6	1	1	52.8	64.8
7	1	3	1, 2, 3	3	8
	2	1	2	28.6	48.6
	3	2	1, 2	48.6	59.6
	4	3	1, 2, 3	59.6	66.6
	5	2	1, 3	68.8	80.3
8	1	2	1, 3	0	7
	2	3	1, 2, 3	14	19
	3	1	1	28.6	45.6
	4	2	1, 2	45.6	54.1
	5	2	1, 3	61.6	68.6
	6	1	3	68.6	90.6
9	1	3	1, 2, 3	0	3
	2	1	1	3	22
	3	3	1, 2, 3	22	28.6
	4	1	1	28.6	35.6
	5	1	2	35.6	50.6
	6	2	1, 2	50.6	61.6
10	1	1	1, 2, 3	7.6	12
	2	1	2	12	23
	3	2	1, 2	29	36.5
	4	1	1	36.5	44.5
	5	2	2, 3	44.5	54.5

CONCLUSION

Production activities play an important role in determining a company’s operating cost. There are more and more orders being made-to-order. During the last decade, a variety of multi-site scheduling techniques have been developed and applied in practice. However, there are few literatures focused on machine tool industries as well as little discussing the hybrid genetic algorithm applied to multi-site scheduling problem. In this study, our objective is derived from real-world scheduling problems. This study would offer multi-site firms an increase in machine utilization, increasing customer satisfaction, and decreasing operational cost. A decision model of an integrated multi-site production scheduling problem is proposed, and a novel heuristic (HGA) approach is also proposed to this problem. Based on the above experiments, the objective value of the HGA consistently outperforms the GA. This study contributes in academic research of management and also in empirical form.

We propose that for future studies, the indicator of scheduling performance, such as the number of tardy jobs or total flow time, could be added into this multi-objective model. The objective value of this study can be further improved by other approaches if the results are used as the basis for a comparison in future studies.

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